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FLUCTUATIONS IN A VACUUM-TUBE OSCILLATOR

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/A Digest/

The relative width of the spectral lines of oscillator fluctuations is about 10^{-10} to 10^{-15}. Obviously, a study of oscillator fluctuations by recording spectrograms is impossible in practice because of the limited resolving power of present-day equipment and because of unavoidable frequency drifts due to dynamic instability. However, there is a more subtle experimental approach to the problem which makes possible the measurement of both amplitude and phase fluctuations of a vacuum-tube oscillator.

In order to measure amplitude fluctuations, one must first introduce the concept of the mean square of the amplitude modulation factor due to chaotic fluctuations and its spectral density. Part of the voltage from the oscillator, having an average amplitude of ($\sqrt{2} \cdot E_0$), is applied to the input of a detector. The output current will also fluctuate and the mean square of the current fluctuation will be a certain function of the mean square of the amplitude modulation factor. The detector current is passed through a certain impedance, generating a voltage drop across it. This voltage is then amplified in the frequency band differential and measured by a squaring instrument, a thermocouple, for example. If the amplifier parameters are known, the mean square of the amplitude modulation factor can be determined. The natural fluctuations of the detector tube can be measured separately and discounted in the calculations. In these experiments (with a 6AC7 detector), however, detector noise is negligible.

The problem of measuring phase fluctuations is considerably more complex, but it was also solved through the use of a unique interference method. The difference of two voltages is applied to the input of the detector. The first

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is taken directly from the oscillator; the second is also taken from the oscillator, but through a nondistorting time-delay circuit, a coaxial cable, for example. An expression for the mean square of the fluctuations of the voltage at the detector input (these fluctuations being a function of both phase and amplitude fluctuations) is derived. Using this expression, the spectral density of the mean square of the modulation factor can be found. Since this quantity is composed of the spectral densities of the mean squares of (1) the amplitude modulation factor and (2) the phase modulation factor and since (1) can be measured by the method indicated above, (2) can be found by subtracting (1) from the spectral density of the mean square of the modulation factor in toto.

To check these theoretical calculations, the fluctuations of an ordinary vacuum-tube oscillator using 6K7 and 6J7 tubes were measured. A frequency of approximately 18 megacycles was used; the circuit capacitance approximated 30 micromicrofarads; the power was less than a watt. The amplifier after the detector was of the superheterodyne type, which permitted measurements in the wide band from 0.5 to 90 kilocycles.

In measuring amplitude fluctuations, it was discovered that if a diode with the usual lead circuit is connected (through a condenser) in parallel with the oscillator circuit, amplitude fluctuations are almost completely eliminated through the indicated band. This phenomenom is of practical interest. It finds its explanation in the theory of diode detection.

An ordinary coaxial cable about 500 meters long was used to measure phase fluctuations; this gave a time delay of approximately 3 microseconds. According to theory, the effective phase fluctuation for 3 microseconds must have been of the order of one angular second when the ratio of the spectral density of the mean square of the phase fluctuation to the spectral density of the mean square of the amplitude fluctuation was approximately 20. In other words, a deviation of the voltages applied to the detector input was easily observed even for a time differential of only approximately 10^{-6} of the wave train length.

The results of the experiment were compared with the theory previously developed by the author for the case of the so-called "isotropic fluctuations" and for the customary idealizations (no grid current or plate reaction). However, since the fluctuations in any real oscillator are "non-isotropic," the theoretical formulas had to be changed slightly; the intensity of chance surges were averaged for the period of oscillation. The accuracy of the experiments was approximately 50 percent.

Comparison of the experiment with theory showed the following:

a. For average oscillation amplitudes (approximately 75 volts), the experiment showed a spectral density of fluctuations 1.2 to 2 times greater than the theoretical at frequencies of from 50 to 90 kilocycles. More particularly, these experiments showed that the spectral density is approximately equal to $15 \cdot 10^{-6}$, instead of $8 \cdot 10^{-6}$ according to theory. However, the spectral density of fluctuations exceeds the theoretical more and more as the frequency is decreased; it is 2-3 times greater than the theoretical for the lowest frequencies.

A study of the results for amplitude fluctuations showed this is mainly due to the flicker effect and that for phase fluctuations it is due to microphonic effect.

b. For large oscillation amplitudes (approximately 150 volts), the experimental value for the spectral density of fluctuations was 3 to 10 times the theoretical value even at frequencies from 50 to 90 kilocycles. These measurements showed that the density was $12 \cdot 10^{-6}$, instead of $3 \cdot 10^{-6}$ according to theory. This increase is apparently due to a marked increase of grid current in the oscillator (probably related to increased fluctuations of this current).

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c. A special amplifier was used to measure the total fluctuation at low frequencies, at which secondary factors, flicker, microphonic effect, etc., become important. The amplifier amplified frequencies from 5 to 10 kilocycles. This measurement showed that secondary factors magnify the over-all amplitude fluctuations 10-30 times the theoretical value. The over-all level of phase fluctuations was 5-20 times the theoretical value. In conducting this experiment, it was noted that even normal conversation at a distance of 5 meters from the equipment, while causing negligible microphonic noise, still produced a very substantial increase in the phase fluctuation level.

The method developed may prove useful in measuring very small phase fluctuations, for example, those appearing in wave propagation.

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